Modeling With Data Assimilation in the North Atlantic (DAMEE)

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LONG-TERM GOALS

To show the strengths and weaknesses of different modeling and data assimilation approaches.

OBJECTIVES

In the past, DAMEE-NAB experiments have addressed the climatological behavior of different prognostic circulation models as per a fixed list of well-documented properties of the North Atlantic Basin. All such experiments have been performed at a low resolution of 1/2 degree with fewer than 20 vertical levels.

Future participants of DAMEE-NAB will address the sensitivity of mesoscale forecasts to variations in climatological measures and will also establish basin-scale predictive capabilities of general circulation models relative to persistence and climatology at higher resolutions (1/10 degree) and a larger number of vertical levels (up to 40). Some other objectives include identifying the strengths and weaknesses of different classes of numerical models and various data assimilation techniques. Exploring and implementing the best data assimilation methods with coupled models would be the final step for accurate, efficient forecasts of the North Atlantic Basin.

APPROACH

The DieCAST model has emerged as being accurate and robust in applications to near-coast features such as boundary currents and shelf break currents and their interactions with deep water eddies. Modeling of such features requires accurate simulation of baroclinic pressure gradient which DieCAST performs successfully, as was found during past studies. More recently, DieCAST has been deployed and validated in different regions of world oceans. Overall, DieCAST has proven to be robust with realistically small diffusivities, unfiltered real topography and realistic density fields. Based on these attributes and past performance, DieCAST will be evaluated with other general circulation models in DAMEE-NAB experiments for model performance and inter-model comparison. A key CAST contributor to this effort was Postdoctoral Assistant Dr. Avichal Mehra.

WORK COMPLETED

Implemented DieCAST on the standard domain for DAMEE-NAB model comparison experiments. To accomplish intermodel comparison, a modified Arakawa "a" grid version of the DieCAST Ocean model was run on the standard domain for DAMEE-NAB experiments stretching from 6 N to 50 N and from

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98 W to 6 W with three degree buffer zones at the northern, southern, and eastern boundaries. Ten-year simulations were carried out with data saved from the last three years of the integration for analysis.

Diagnostics were obtained from three-year time-averaged results from the ten-year simulations. They indicated good agreement with Levitus 1994 Climatology which was used for initialization of the model, even though the open boundaries had to be artificially closed as per DAMEE-NAB specifications.

Parameter sensitivity studies were also conducted in the NAB using DieCAST [Mehra and Dietrich, 1998a]. These included the influence of vertical resolution on the thermocline and other flow features, the effect of drag co-efficient on Florida Strait transport, and a comparison of results with different wind stress climatologies. A new surface restoring condition, derived from an atmospheric energy balance model, was also implemented.

The vigorous water mass transformation in the Labrador and GIN Seas strongly affects the thermohaline circulation of the entire NAB. This water mass transformation was addressed by maintaining a diagnostic time mean of model surface heat and salinity fluxes at all horizontal grid points; adding the long term mean model heat and salinity heat fluxes to the surface layer each time step; after adding the long term mean fluxes, restoring to Levitus 1994 Climatology with O(180) day restoring time scale at each time step; and using the streamfunction for the zonally averaged flow to diagnose thermohaline effects on the meridional circulation.

RESULTS

Properties evaluated for performance assessment of the model, from results obtained on the standard domain, included vertical cross-sections of temperature and salinity, Florida Strait transport, SST and SSH means, and mean and eddy kinetic energy distributions. These results were compared and evaluated against available observations, Levitus 1994 Climatology, and other models. This comparison will appear in a future special issue of Deep Sea Research on the DAMEE-NAB.

DieCAST was also implemented at 1/3 degree resolution on an extended North Atlantic domain from 15 S to 75 N and from 98 W to 15 E [Mehra and Dietrich, 1998a]. The larger domain was desirable to provide more realistic water mass transformation time scales and associated dynamic effects on the NAB thermohaline circulation. Results showed many realistic detailed features including sustained Gulf Stream separation near Cape Hatteras; an active transient eddy field north of the Gulf Stream with many pinched off warm core eddies; all three branches of the Labrador Current; a prominent persistent anticyclonic Taylor column over the Flemish Cap; a small semi-permanent cyclone pair in the southeastern Flemish Cap region; narrow Gulf Stream water mass elements that enter a loop current between the cyclonic pair, with the loop regularly pinching off eddies into the Labrador Sea thus ventilating the North Atlantic Gyre in a similar way that large core eddies ventilate the Gulf of Mexico; North Brazil Current with retroflection eddies; and a cyclonic western Mediterranean Sea gyre.

To parameterize Arctic Basin water mass transformation, a buffer zone along the northern boundary of the modeled region was used in the 1/3 degree model. A northern Gulf Stream water branch jetted to the NE corner of the modeled region, but turned sharply westward in the buffer zone where its water mass was quickly restored to climatology. An alternative to this short-circuited Arctic water mass transformation is to open the NE corner for outflow and specify an East Greenland Current inflow (return flow from Arctic basin). In the reduced DAMEE-NAB standard domain, the Arctic Basin, GIN

Sea, and Labrador Sea water mass transformations were parameterized by a buffer zone near 50 degrees North.

The main focus of the data assimilation development effort was to ingest the satellite data on regular SSH observations. The primary concern was to develop an objective methodology to project the surface information to subsurface levels, so that the overall numerical state of the system stayed in an approximate dynamical balance. Any small anomalies from the balance were expected to dissipate in a few steps of model integration. The approach was to use optimum interpolation (OI) of the observed satellite SSH, followed by geostrophic adjustment of the subsurface current velocities due to changes induced by the differences in the observed SSH from the model SSH. This adjustment was facilitated by the use of correlation factors obtained between SSH and subsurface hydrography at model grid points. To complete this task, details of the OI method are presently being investigated by application to the standard DAMEE-NAB domain using Topex/Poseidon data for Calendar Year 1993. Results with and without data assimilation will be evaluated at suitable model grid points against available XBT/CTD data for the same year.

IMPACT/APPLICATION

A major impact of this research is it demonstrates that DieCAST realistically simulates detailed coastal and deep-water features using lower resolution and significantly less computing than required by other ocean models. This is due to using fully fourth-order accurate numerical schemes, which have very low numerical dispersion, and are uniquely robust with realistic unfiltered topography and realistically small viscosities.

TRANSITIONS

In FY98, we delivered diagnostics in the North Atlantic Basin for inter-model comparisons, with results submitted to a refereed journal [Mehra and Dietrich, 1998b].

RELATED PROJECTS

This project was directly leveraged by ONR Research Grant N00014-97-1-0525 to CAST for Modeling the Santa Barbara Channel Using Realistic Open Boundary Conditions and Winds.

This project was also significantly leveraged by other ongoing research efforts, both nationally and internationally. For example, Texas A & M University and NRL Stennis are collaborating for general modeling of the Gulf of Mexico using DieCAST, the University of Auckland has adapted DieCAST and its new numerics as the New Zealand Regional Model, the New Zealand Electric Company uses DieCAST for the high resolution Doubtful Sound Model, Dalhousie University is working on adding data assimilation to the DieCAST version in the Gulf of St. Lawrence and Grand Banks Region, NRL Stennis Space Center is using DieCAST for high resolution modeling of Adriatic Sea nested within a 1/8 degree Mediterranean Sea DieCAST model and for coupled Ice-Sea Modeling in the Arctic, Bedford Institute of Oceanography is investigating DieCAST performance in coastal zones and in the North Atlantic, NOAA National Marine Fisheries Service has used DieCAST in the Gulf of Mexico to study algal blooms, University of New South Wales is using DieCAST to run simulations for the East Australian Current and Tasman Sea, Australian Defense Forces Academy is running simulations in the Hawaiian Island area using DieCAST, NOAA Great Lakes Environmental Research Laboratory has configured DieCAST to run simulations in Lakes Erie and Michigan, Memorial University is using

DieCAST for simulations in Newfoundland Bay, Florida State University has coupled DieCAST to an atmospheric model to investigate hurricane response, MIT and Canadian Meteorological Center have coupled DieCAST to the Canadian operational meteorological model, Naval Postgraduate School is using DieCAST to model the California Current, and Oregon State University is developing high resolution Southern Hemisphere and global scale versions of the DieCAST Ocean Model. Some other collaborations involve James Cook University, University of Trieste in Italy, UIB at Palma in Spain, Government of Bulgaria, Russian Federation, University of Otago and Leigh Laboratory in New Zealand, and CSIRO in Australia.

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